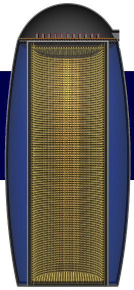
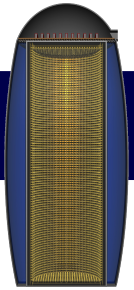

The LENA Neutrino Observatory

Björn Wonsak

for

the LENA Collaboration

Universität Hamburg

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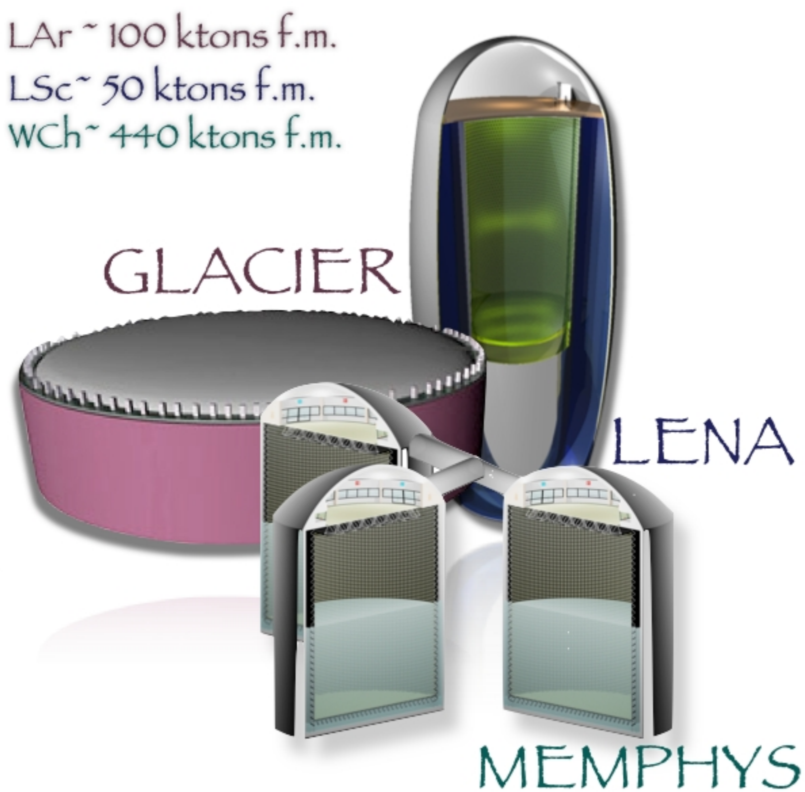
LAGUNA

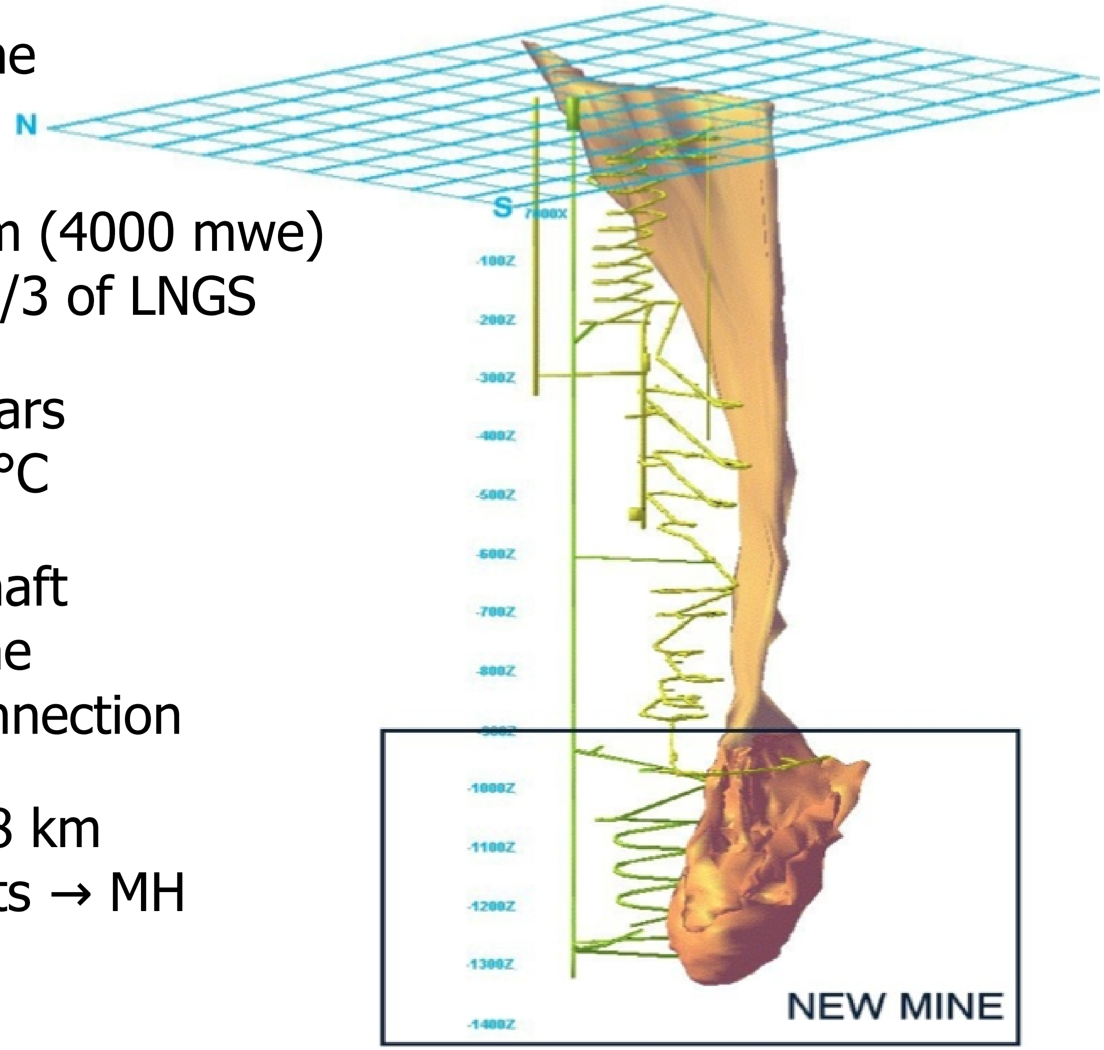
- Consortium of European science institutions and industry partners
- Design studies funded by the European Community (FP7)
- **LAGUNA:** detector site, cavern, and oscillation baselines (2008-11)
- **LAGUNA-LBNO:** detector tank, instrumentation, and beam source (2011-14)



LENA at Pyhäsalmi

Pyhäsalmi Mine:

- Active copper/zinc-mine
  in central Finland
- Deepest level: -1450 m (4000 mwe)
  → muon flux about 1/3 of LNGS
- Old bedrock: $3x10^9$ years
  → very hard, dry, 23°C
- Access: elevator shaft
  road decline
  railway connection
- Baseline to CERN: 2288 km
  → large matter effects → MH



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LENA Detector Layout

Liquid Scintillator:
~69 kton LAB

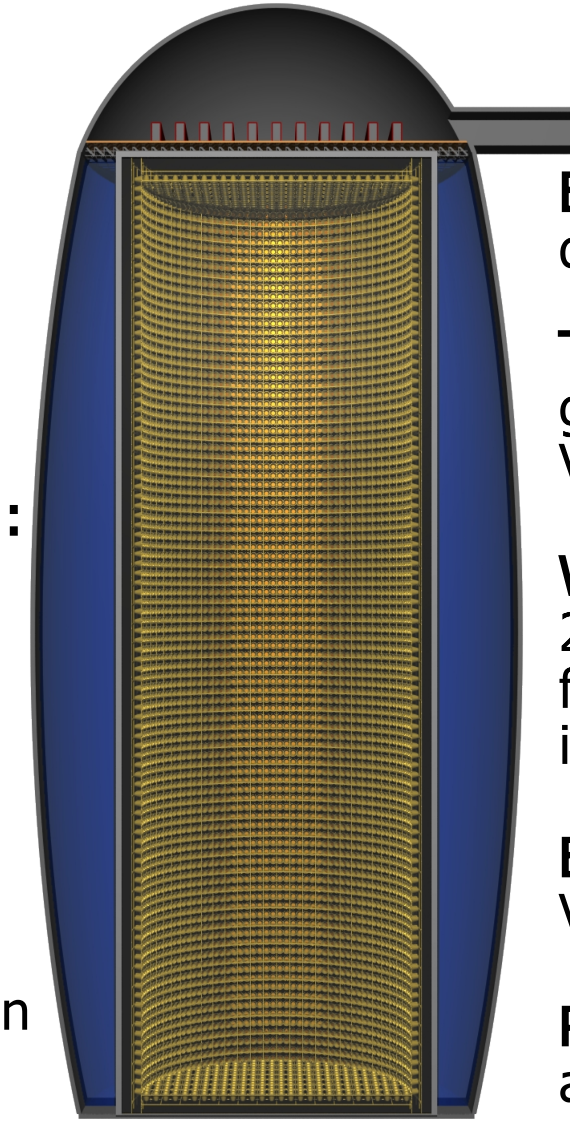
Concrete tank:
r=16 m, h=100 m

PMT support structure:
r=14 m

32000 12'' PMTs
light concentrators
→ 30% optical coverage

Optical shield

Active volume: ~50 kton



Electronics hall:
dome of 15 m heights

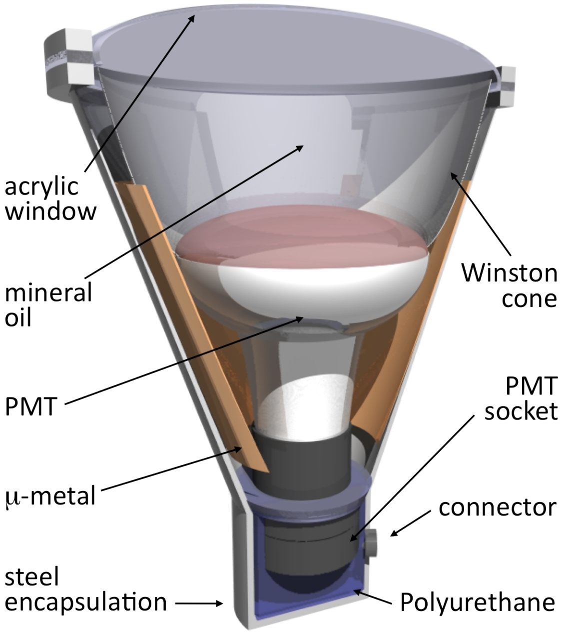
Top muon veto:
gas/solid scint. Panels
Vertical muon veto

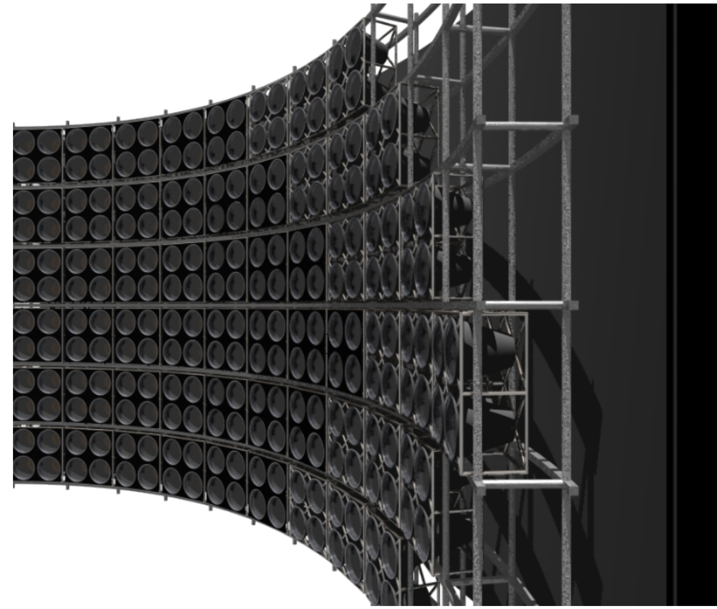
Water Cherenkov veto:
2000 PMTs, $\Delta r > 2$ m
fast neutron shield
inclined muons

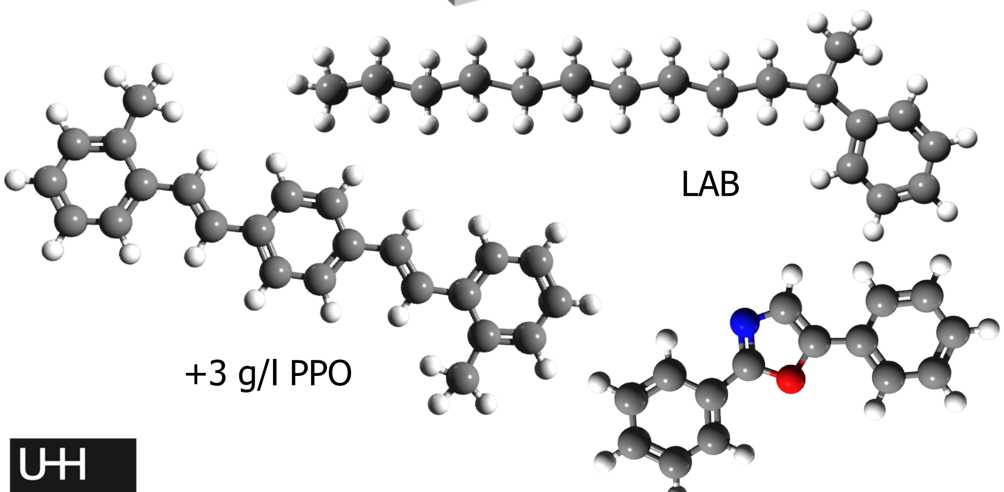
Egg-shaped cavern:
$V \approx 10^5\ m^3$

Rock overburden:
at least 4000 mwe

LENA: A Mature Project



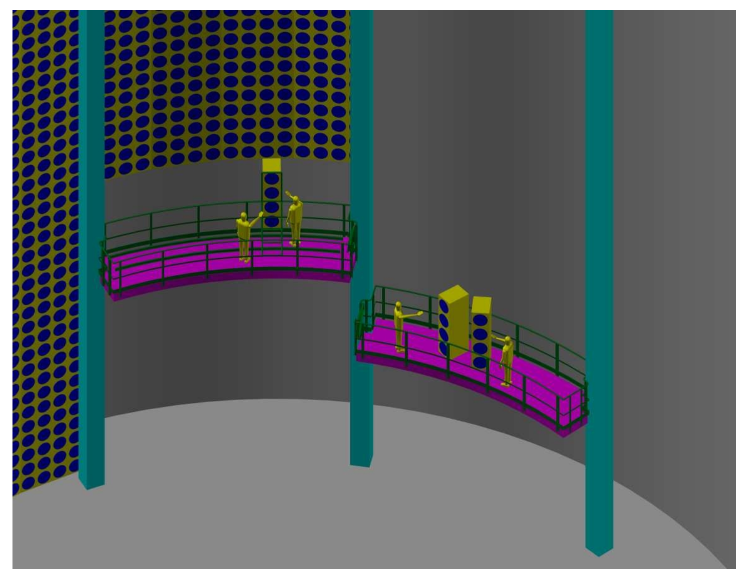




LAB

+3 g/l PPO

+20 mg/l bisMSB



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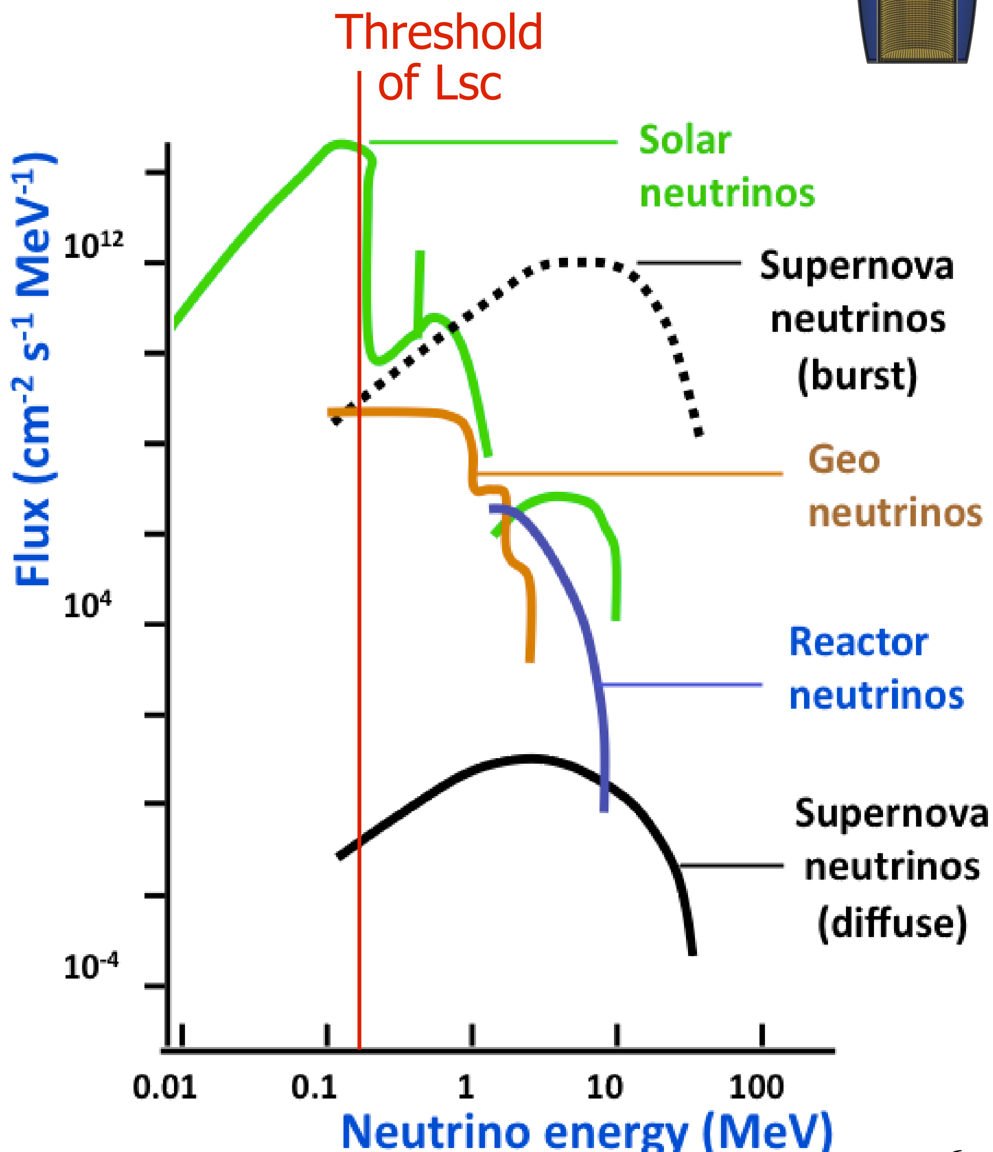
LENA Physics Program

Neutrinos at low energies

- Galactic Supernovae
- Diffuse SN ν background
- Solar neutrinos
- Dark matter annihilation
- Geoneutrinos
- Reactor neutrinos
- Radioactive sources
- Pion decay-at-rest beams

GeV energies

- Long-baseline neutrino beam
- Atmospheric neutrinos
- Proton decay into $K^+\bar{\nu}$

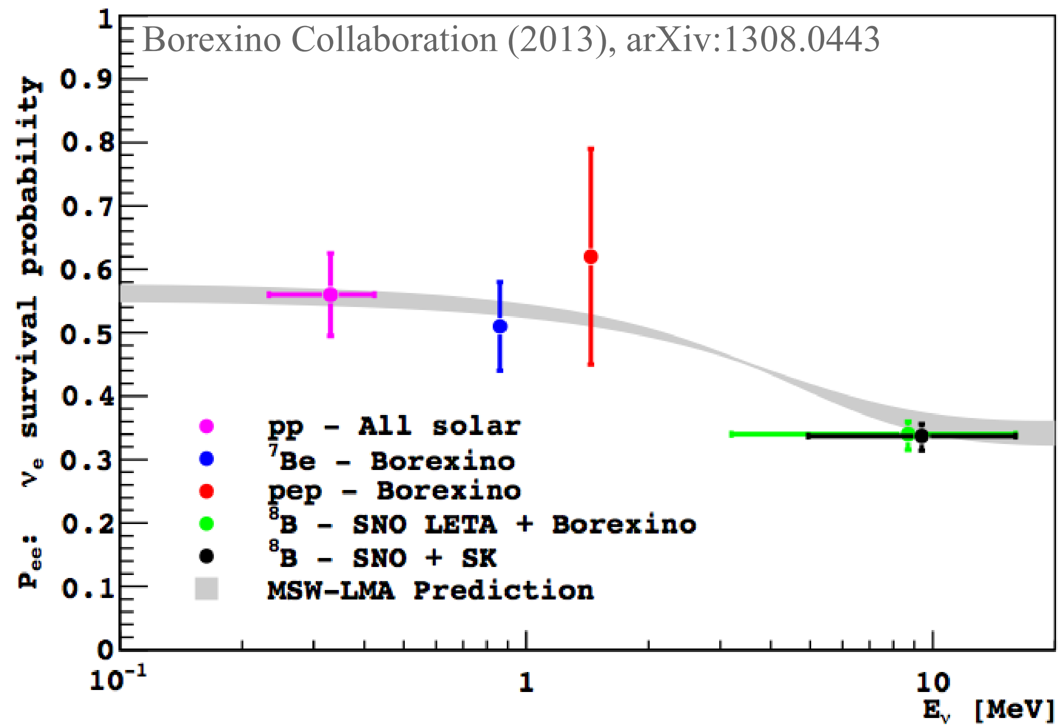


Solar Neutrinos I

Fiducial mass: 30 kt
to reduce γ background

Expected flux:
10000 events per day
200 CNO ν per day

→ Oscillation physics:
Test transition region of MSW effect



Upturn of ^{8}B spectrum visible with 5 σ after 5 y in LENA!

PhD. Thesis Randolph Möllenberg, TU München 2013

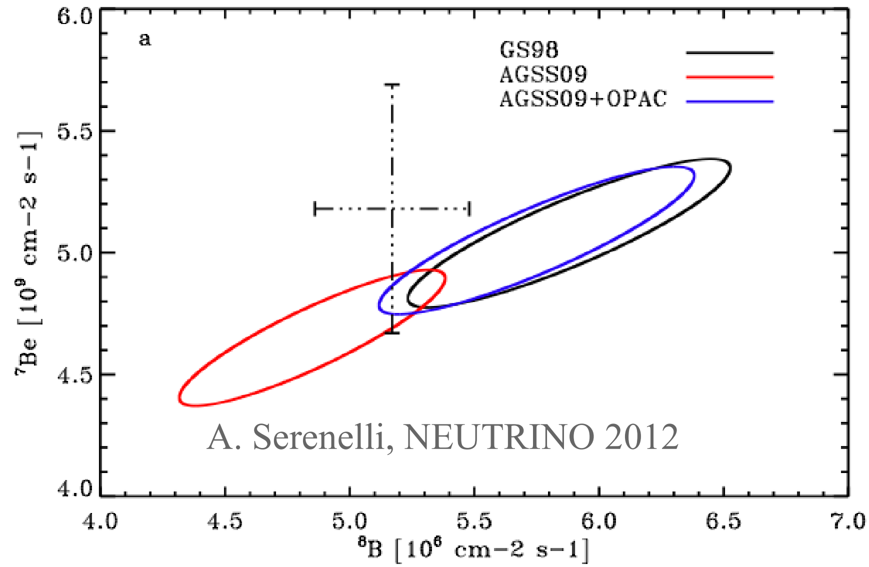
Solar Neutrinos II

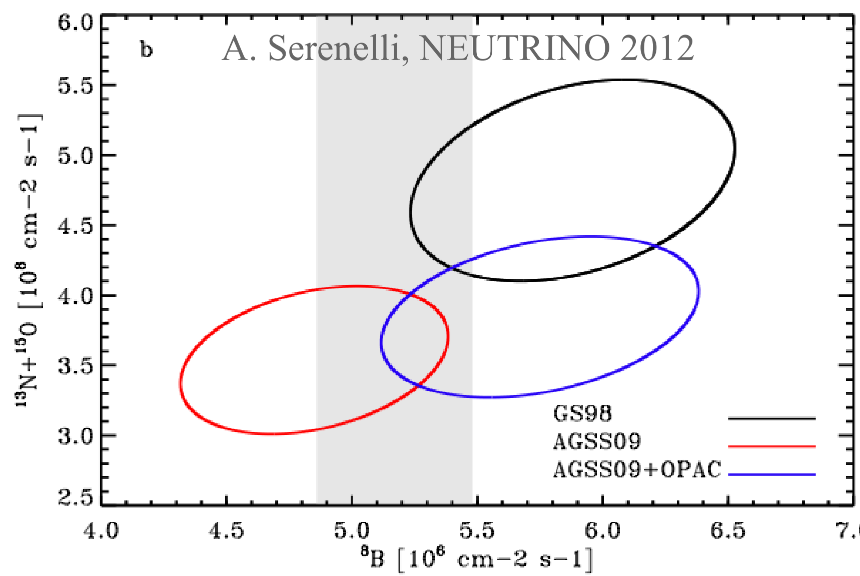
Solar properties:

- Precise determination of solar neutrino rates

→ Solve solar metallicity problem

- Search for time variations in flux



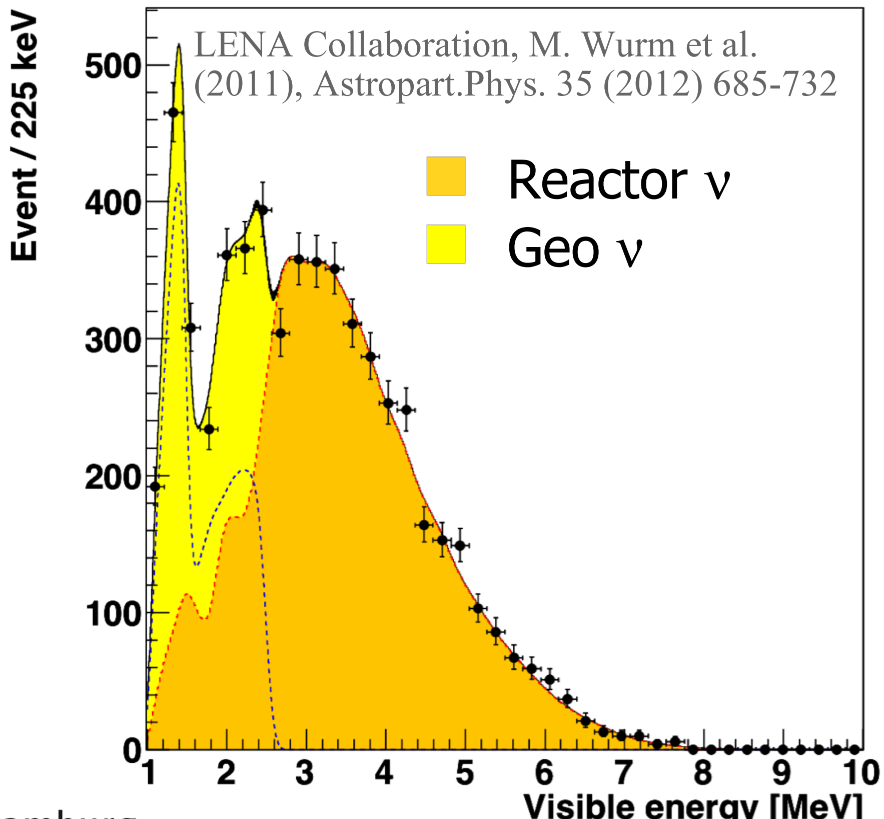


Geo Neutrinos

- 10 years LENA: 5-6% precision of U/TH flux ratio, 1% on total flux

→ Abundances and distribution of radioactive elements in Earth

→ Test radiogenic contribution to the heat flux of Earth



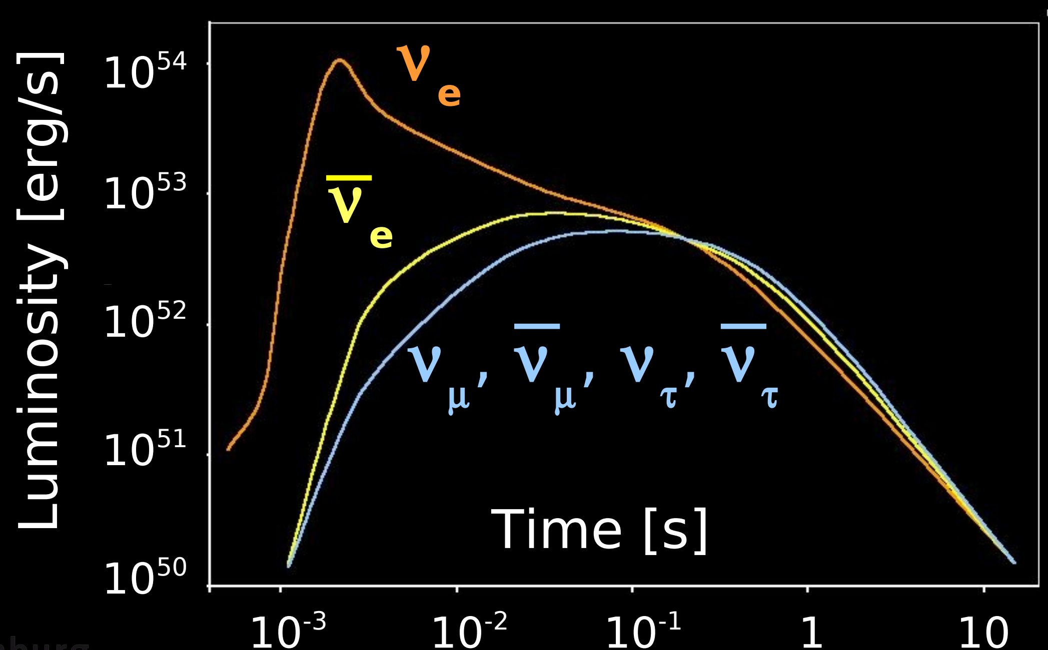
1 y LENA at Pyhäsalmi with future reactors

Galactic Supernova Neutrinos

10-15 M_{Sol} SN in galactic center → **15000 events in LENA**

- Core collapse → ν_e burst
- Accretion and cooling phase → $\nu/\bar{\nu}$-pairs

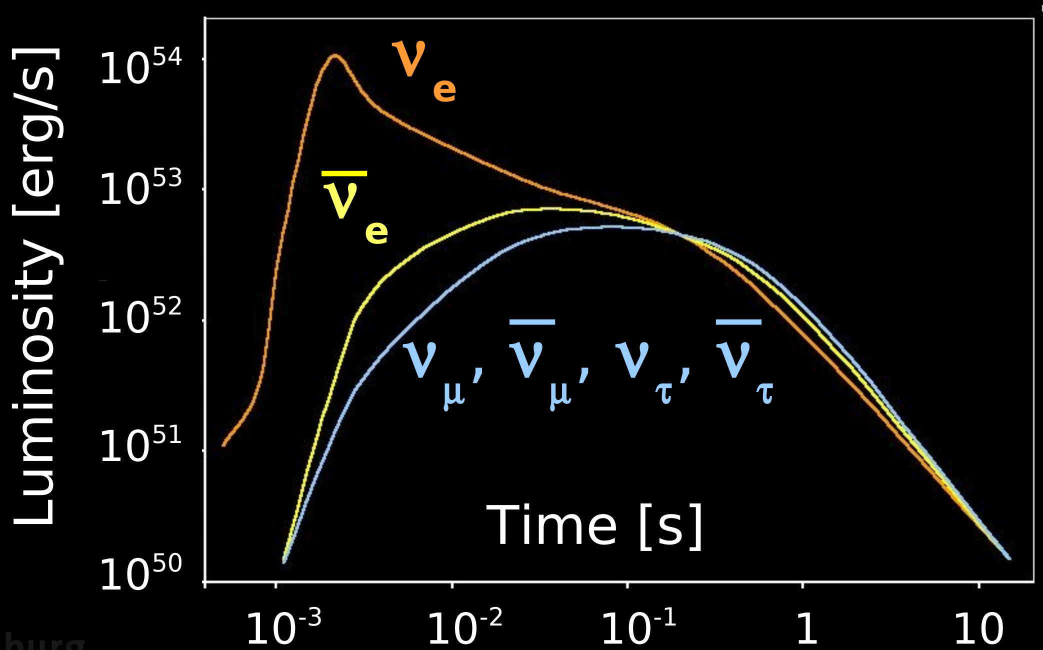
2-3 galactical SN expected every 100 years



Galactic Supernova Neutrinos

Different detection channels for individual neutrino types
→ Energy and flavor resolved analysis of arrival time

→ Test SN-models



Galactic Supernova Neutrinos

Different detection channels for individual neutrino types
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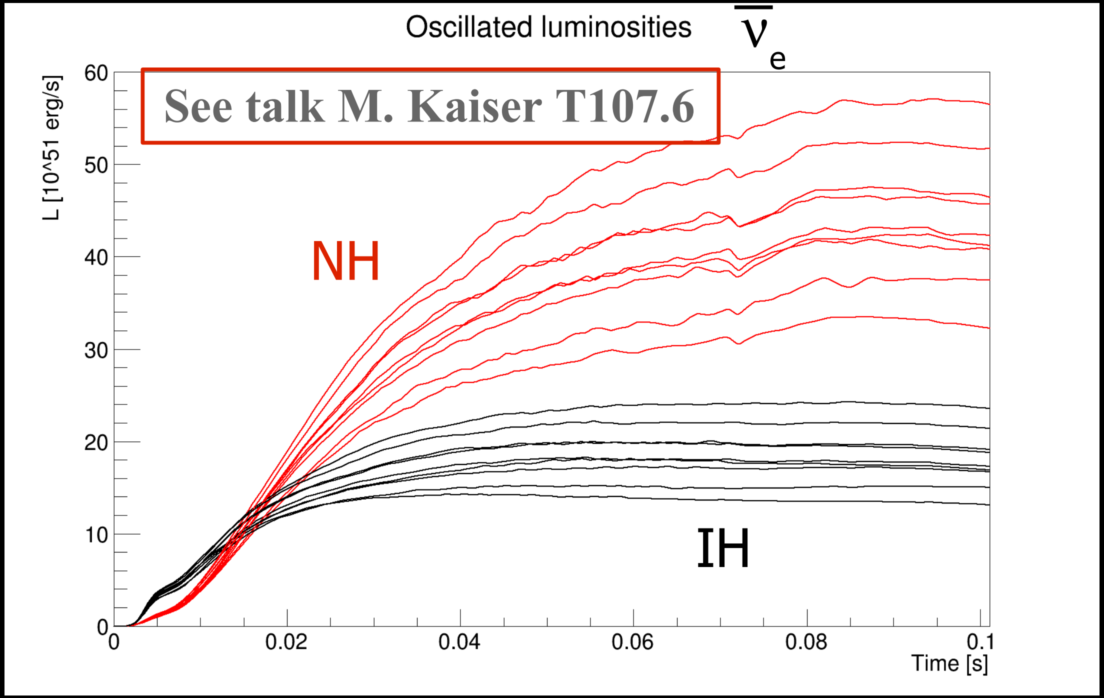
→ Test SN-models

+ Oscillations of SN ν's sensitive to mass hierarchy



Galactic Supernova Neutrinos

Different detection channels for individual neutrino types
→ Energy and flavor resolved analysis of arrival time

→ Test SN-models

+ Oscillations of SN ν's sensitive to mass hierarchy

Some sensitivity to Si-burning → great for SNEWS

Diffuse SN Neutrino Background

Sum of all SN on cosmic scale
→ Isotropic neutrino background

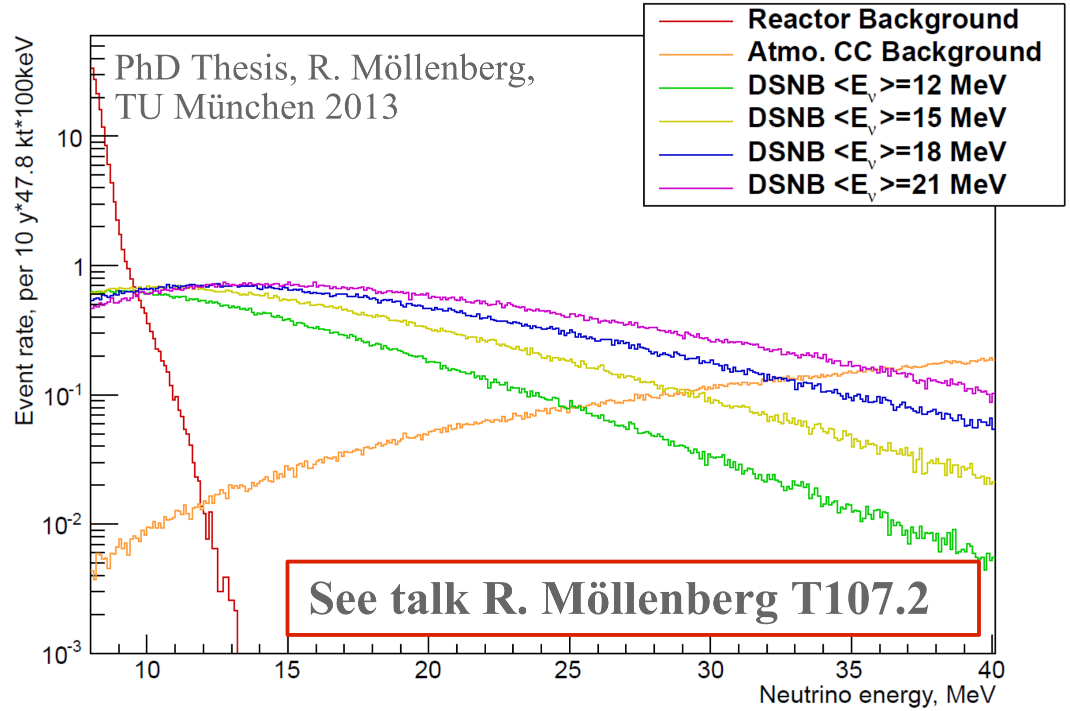
- Average neutrino spectrum red-shifted by cosmic expansion

→ Information on star formation rate & SN models

Expected flux: ~100 ν/s/cm²

Not yet observed

LENA: 2 - 20 events per year



Long-Baseline Neutrinos

Distance CERN to Phyäsalmi: 2288 km

→ Large matter effects → Good for mass hierarchy

Suggested exposure: 1.5x10^{21} pot (50% ν and 50% $\bar{\nu}$)

→ Statistical power > 95% to keep true mass hierarchy if the other should be excluded with 3 σ

Low NC-background rejection efficiency in LSc

→ No competitive sensitivity to δ_{CP}

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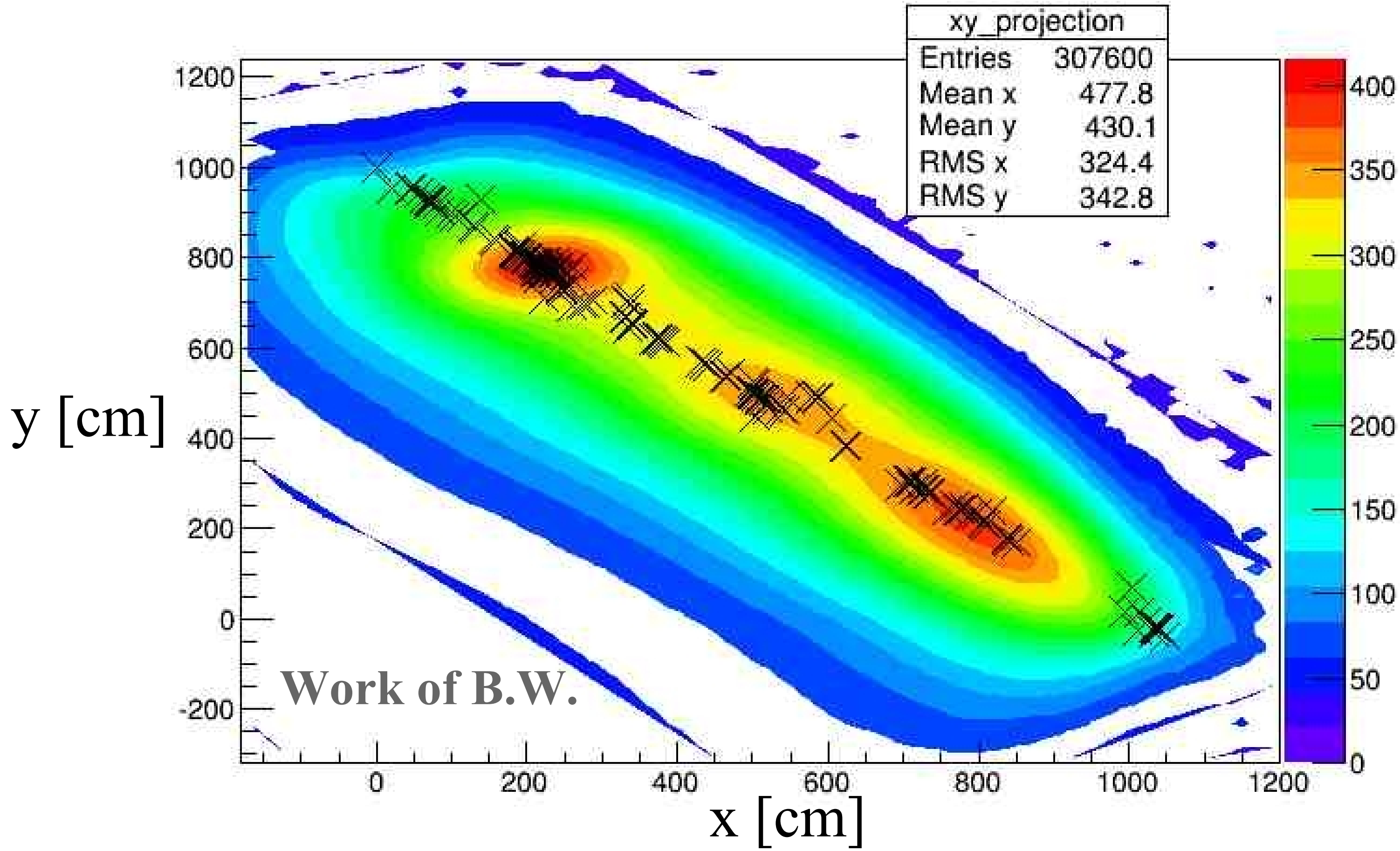
Work in progress
→ Final efficiencies not yet known!

Low NC-background rejection efficiency in LSc

→ No competitive sensitivity to δ_{CP}

Tracking in LENA

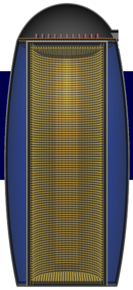
Uses full time-distribution of each PMT

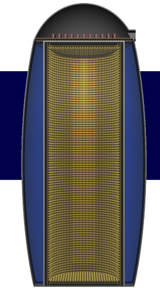


See also talk of D. Hellgartner T40.4

Measurement of dE/dx seems possible!

Atmospheric Neutrinos

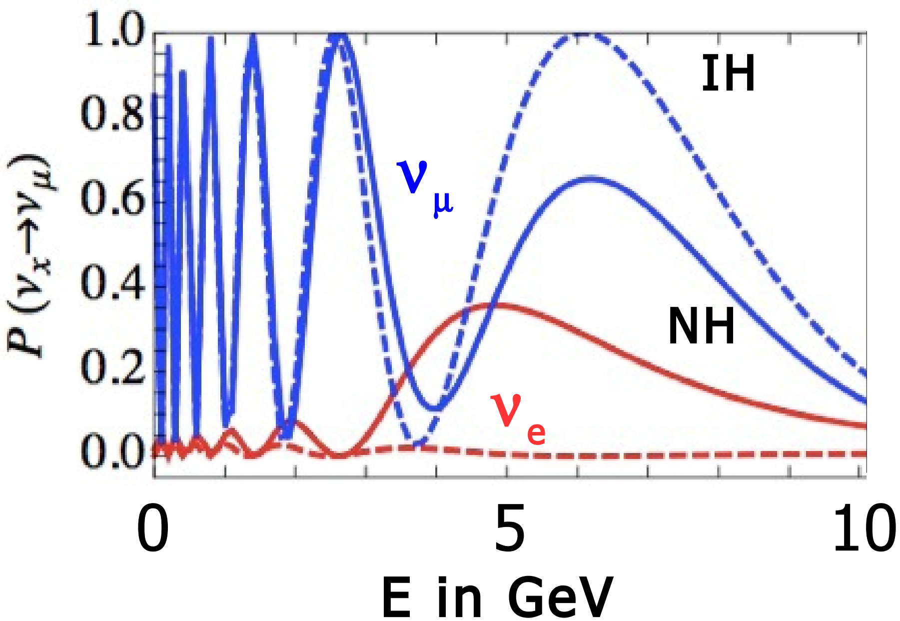


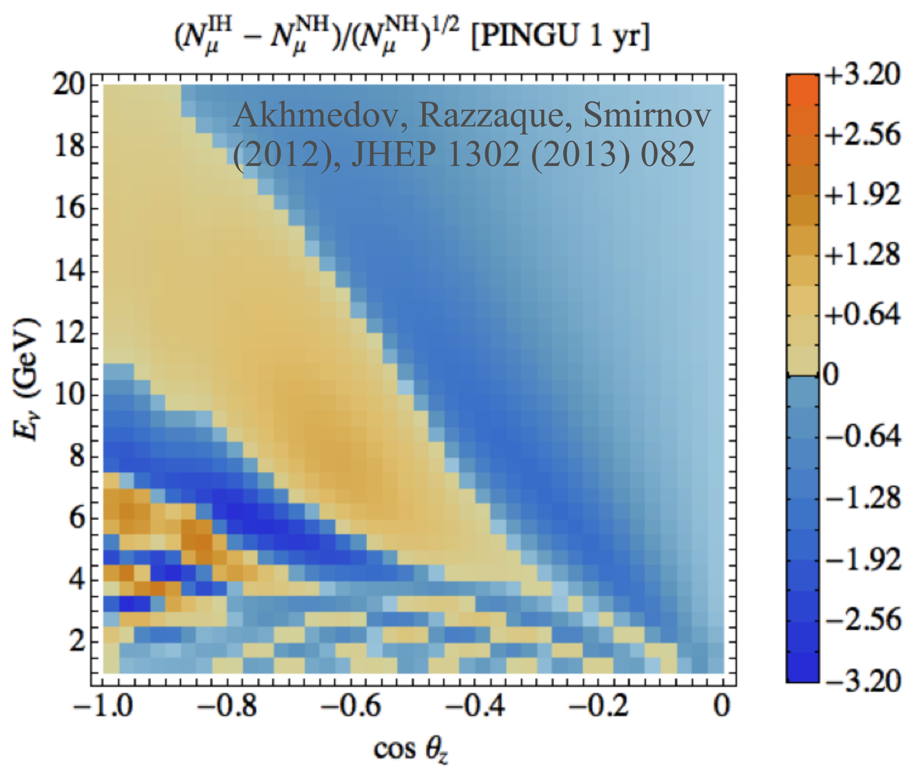


Oscillation physics:

See talk M. Soiron T74.7

- Large matter effects → Clear signature for mass hierarchy
- Lower mass than e.g. PINGU/ORCA → Less statistic
- Better energy resolution → Resolve low energy minimums



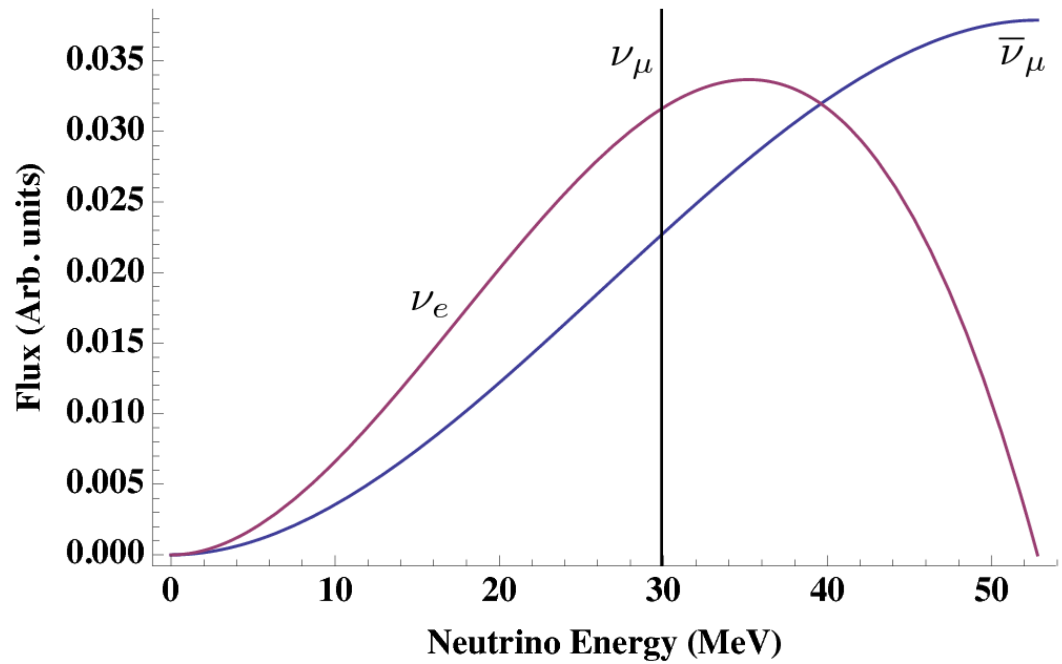


DAEδALUS

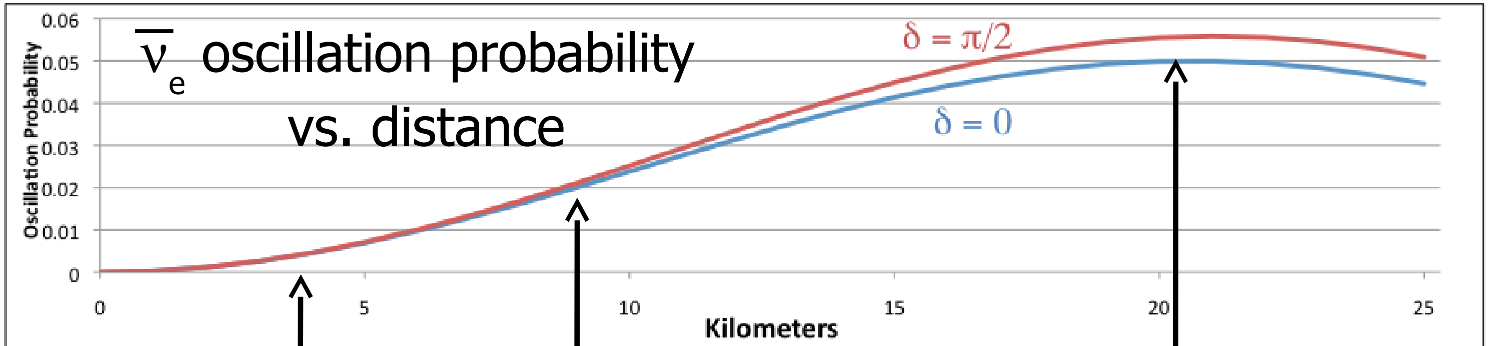
@LENA

Decay-at-rest ν-source:

- Small uncertainties on spectrum
- Almost no $\overline{\nu}_e$ contamination



DAEδALUS Concept

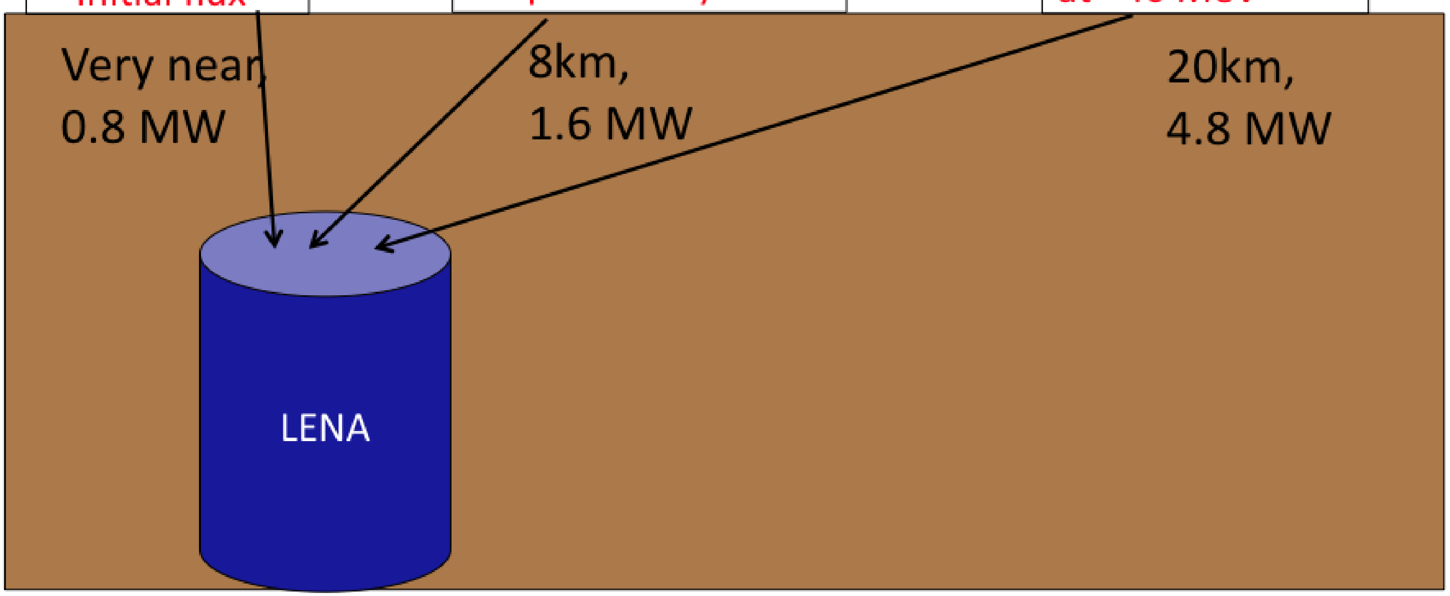


Constrains Initial flux

Constrains rise of probability wave

Osc. maximum at ~40 MeV

Cyclotron distance & power



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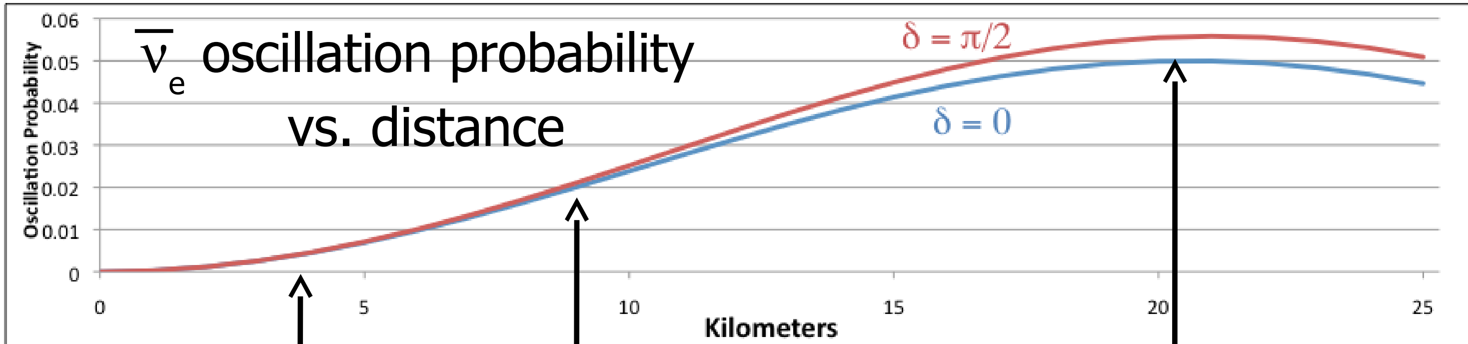
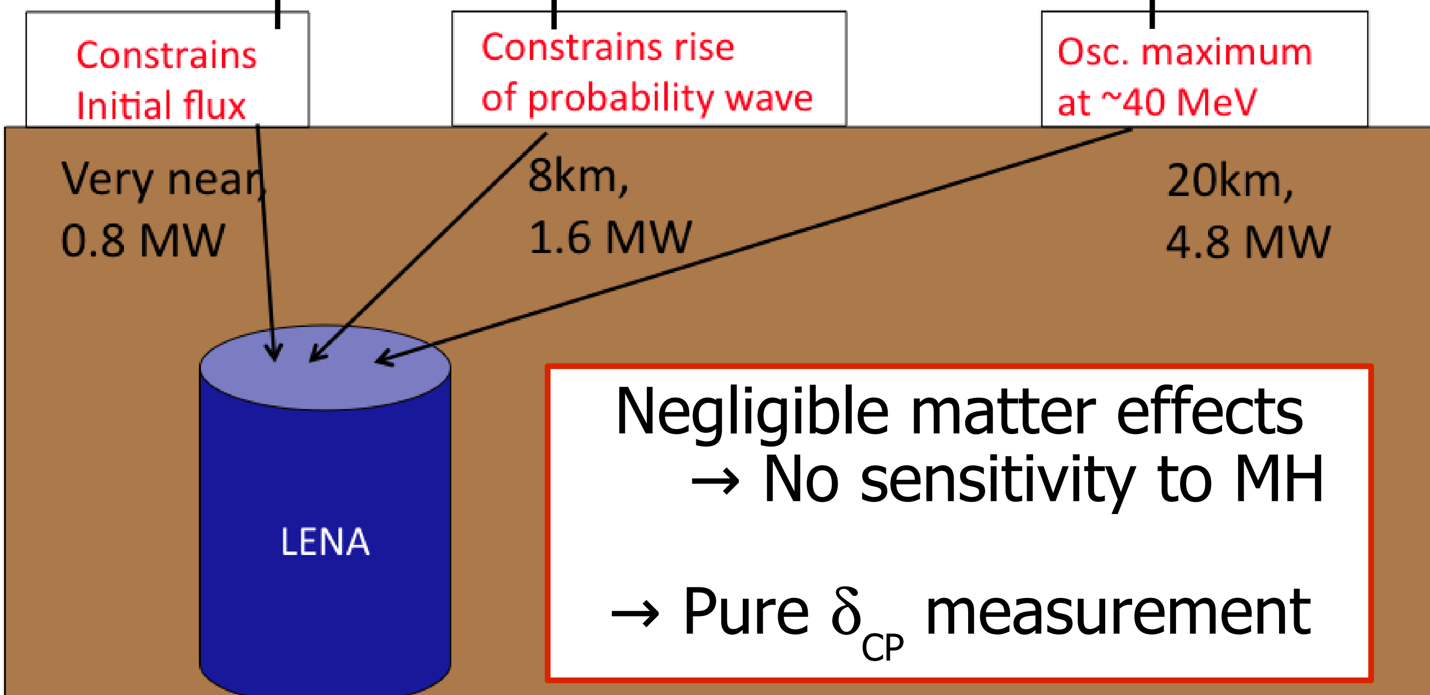
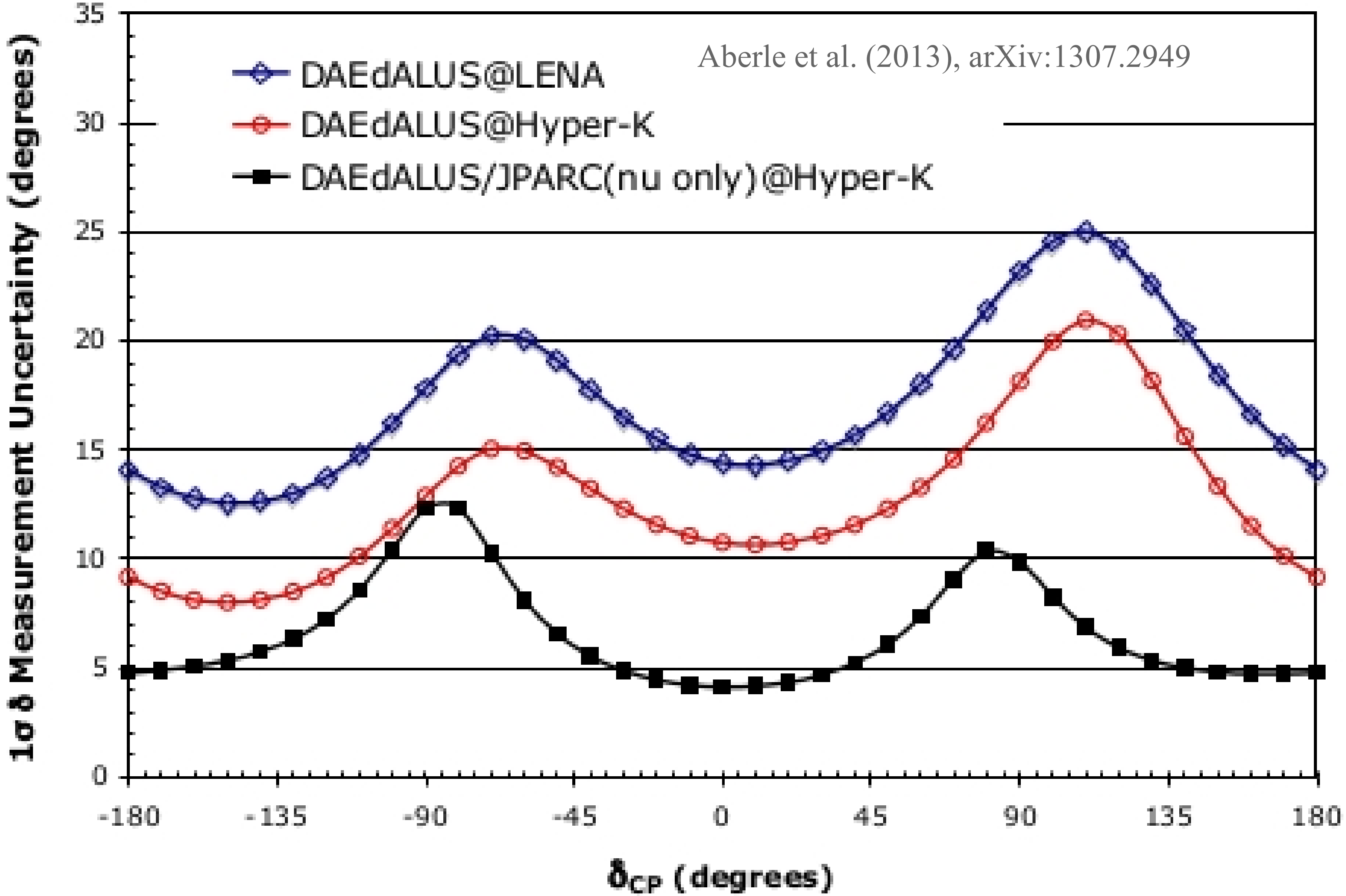
DAEδALUS Concept

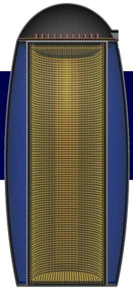


Cyclotron distance & power

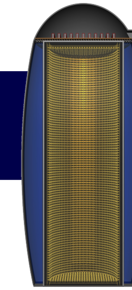


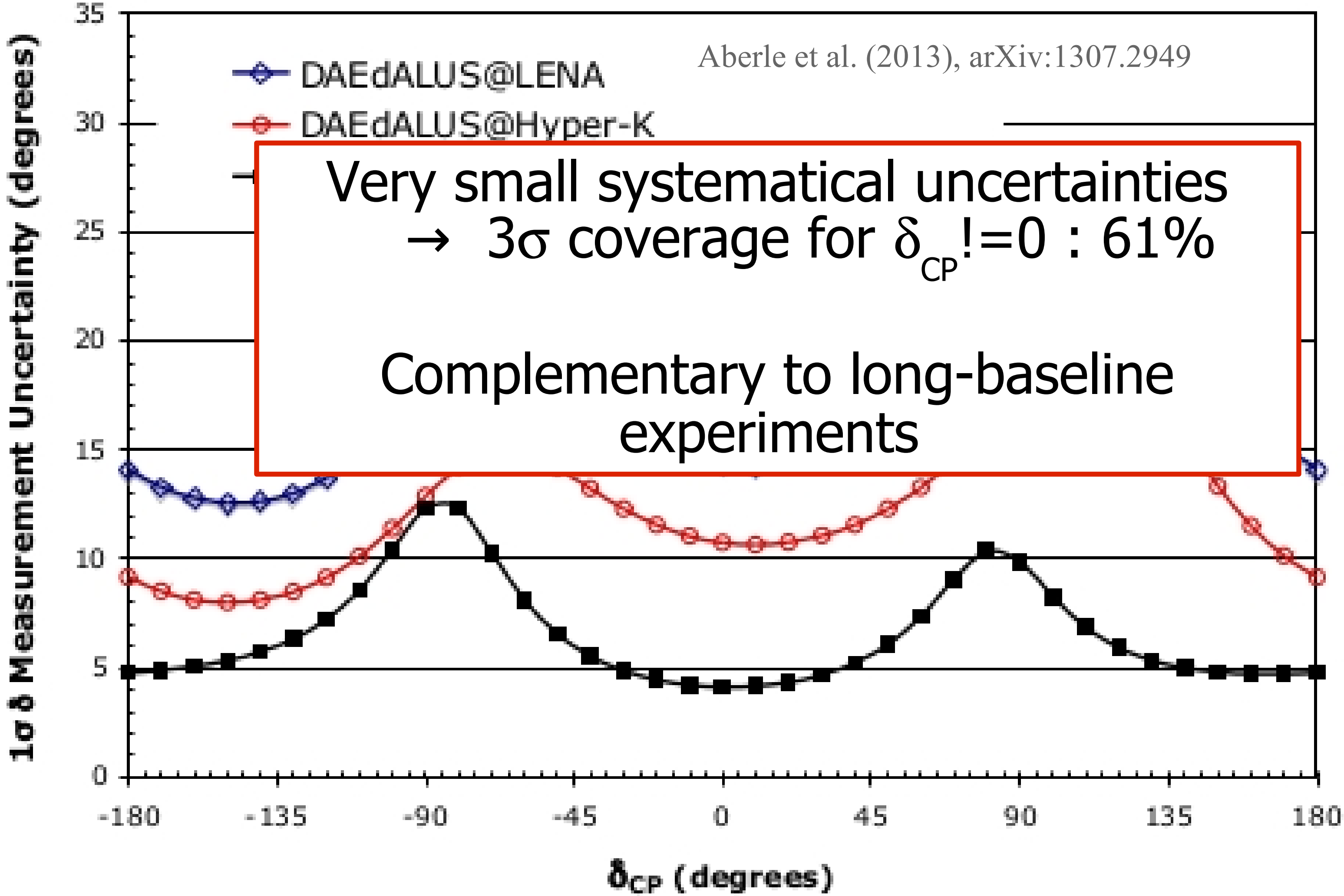
DAEδALUS Physics Potential





DAEδALUS Physics Potential





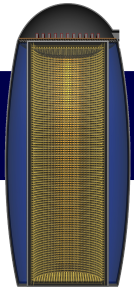
Very small systematical uncertainties
→ 3σ coverage for δ_{CP}!=0 : 61%

Complementary to long-baseline experiments

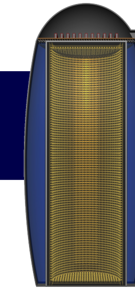
Conclusions

- LENA is a very mature project
- Extremely rich low energy physics program

- Some sensitivity on MH at higher energies
- Significant progress with tracking in the GeV range
- DAEδALUS at LENA = highly competitive δ_{CP} search



LENA related Talks



- Randolph Möllenberg, T107.2 (SN in LENA)
- Markus Kaiser, T107.6 (SN in LENA)

- Björn Wonsak, T11.4 (Tracking in LENA)
- Sebastian Lorenz, T11.5 (Tracking in LENA)

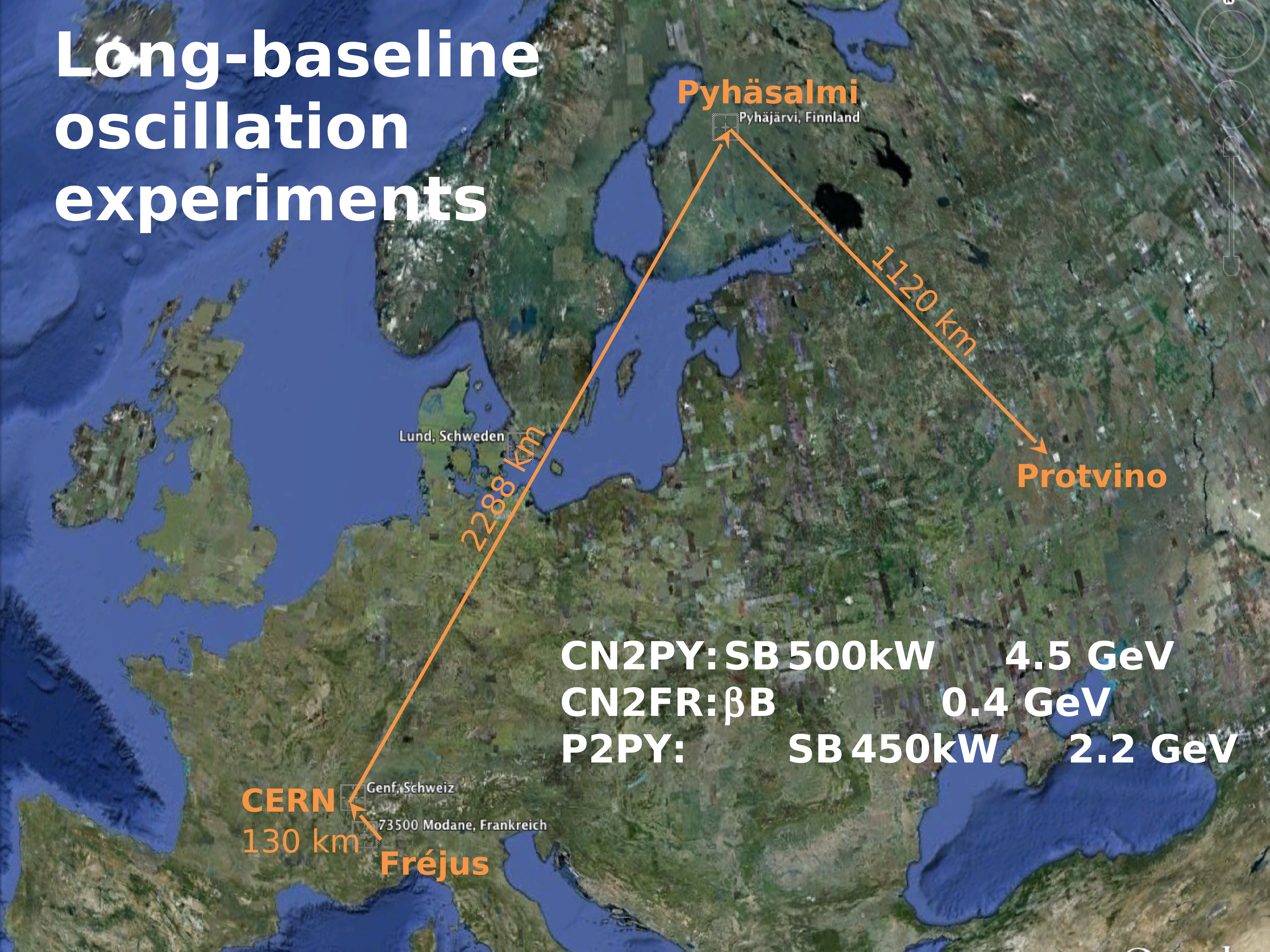
- Dominikus Hellgartner, T40.4 (Tracking in Borexino)

- Michael Soiron, T74.7 (Atmosherische ν in LENA)

- Julia Sawatzki, T74.8 (JUNO)

Backup Slides:

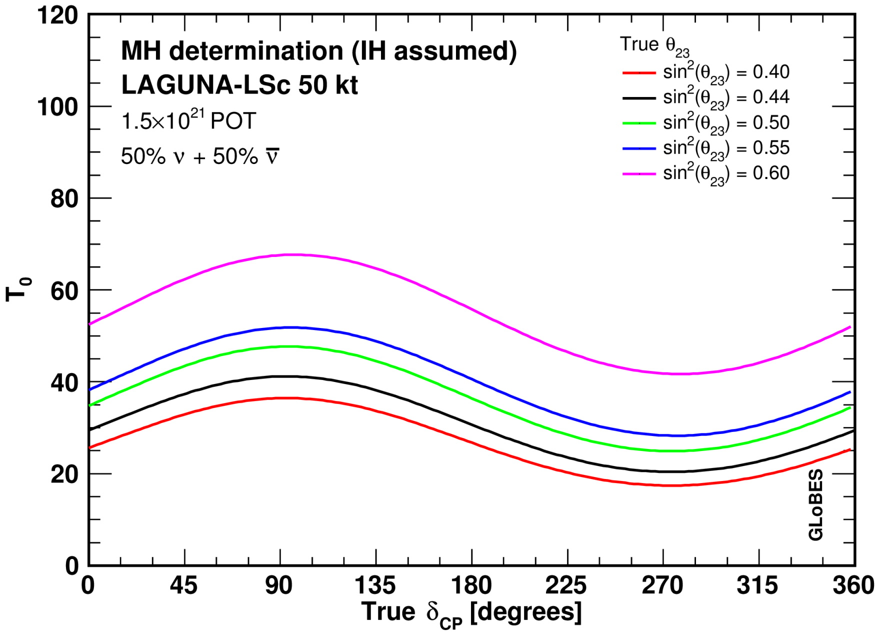
Long-baseline oscillation experiments

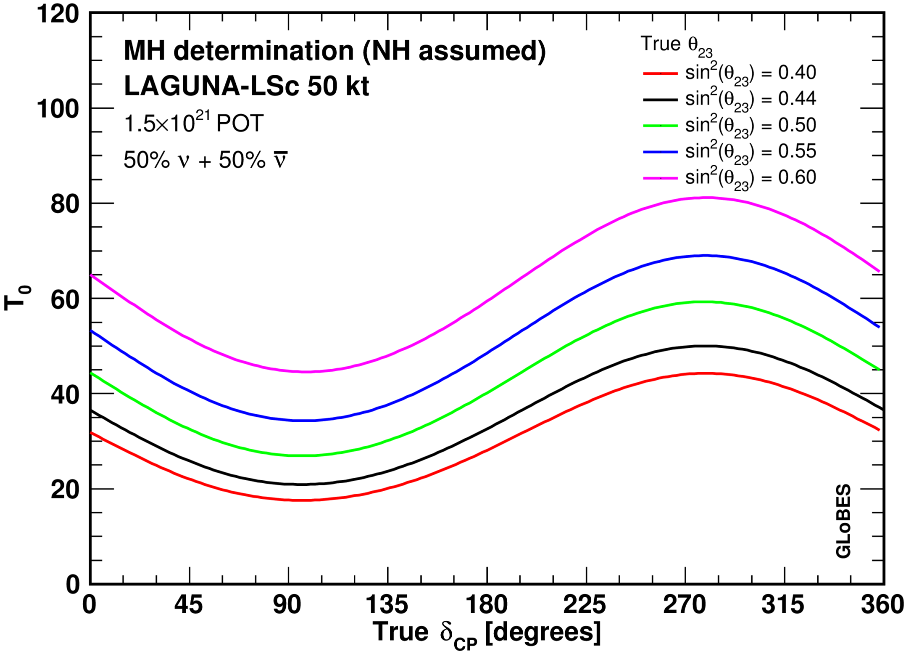


CN2PY: SB 500kW 4.5 GeV

CN2FR: βB 0.4 GeV

P2PY: SB 450kW 2.2 GeV


MH determination (IH assumed)
LAGUNA-LSc 50 kt
1.5×10^21 POT
50% ν + 50% ν̄
True θ23
sin²(θ23) = 0.40
sin²(θ23) = 0.44
sin²(θ23) = 0.50
sin²(θ23) = 0.55
sin²(θ23) = 0.60
T0
True δCP [degrees]
GLoBES
0
20
40
60
80
100
120
0
45
90
135
180
225
270
315
360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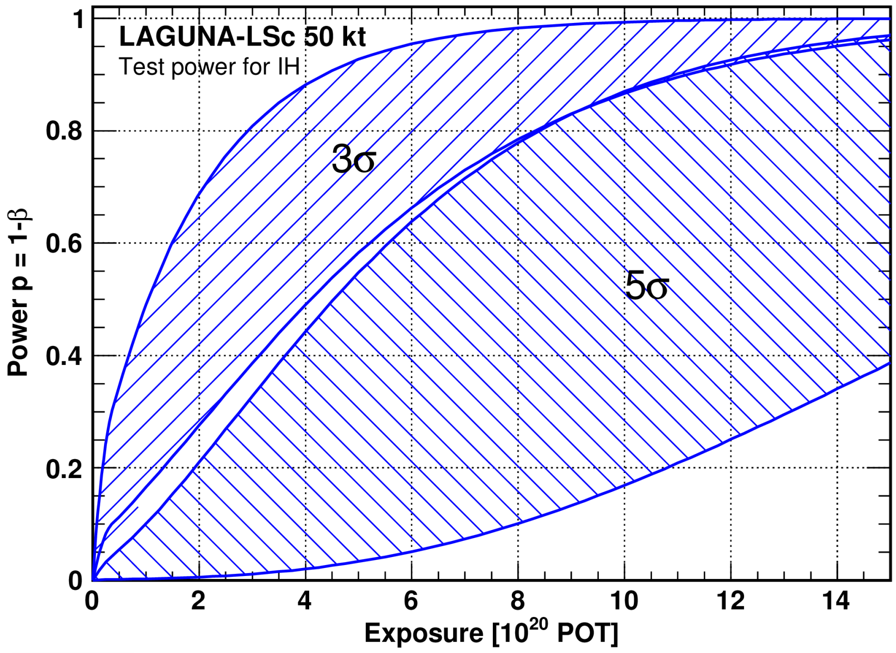
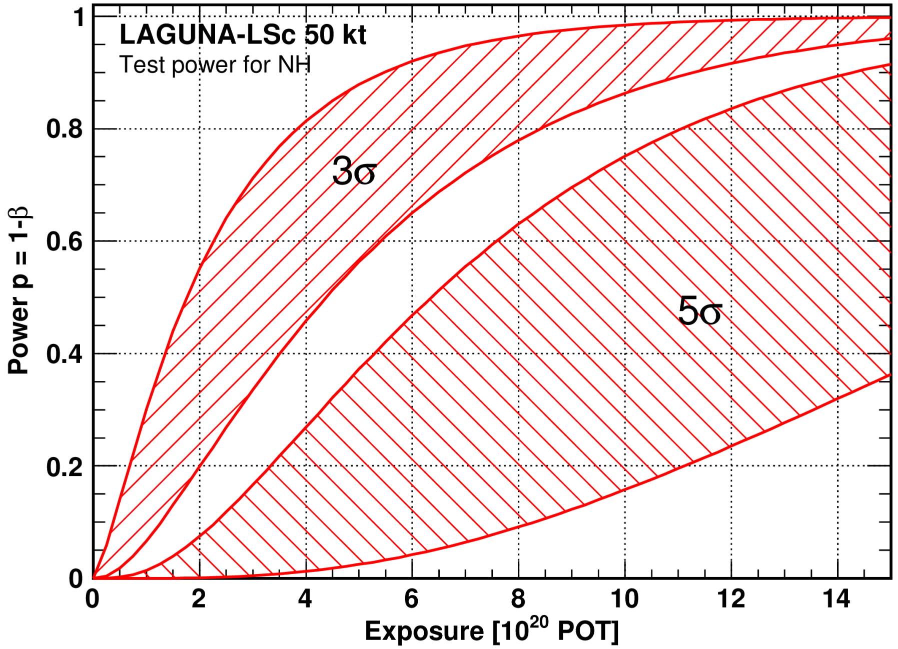
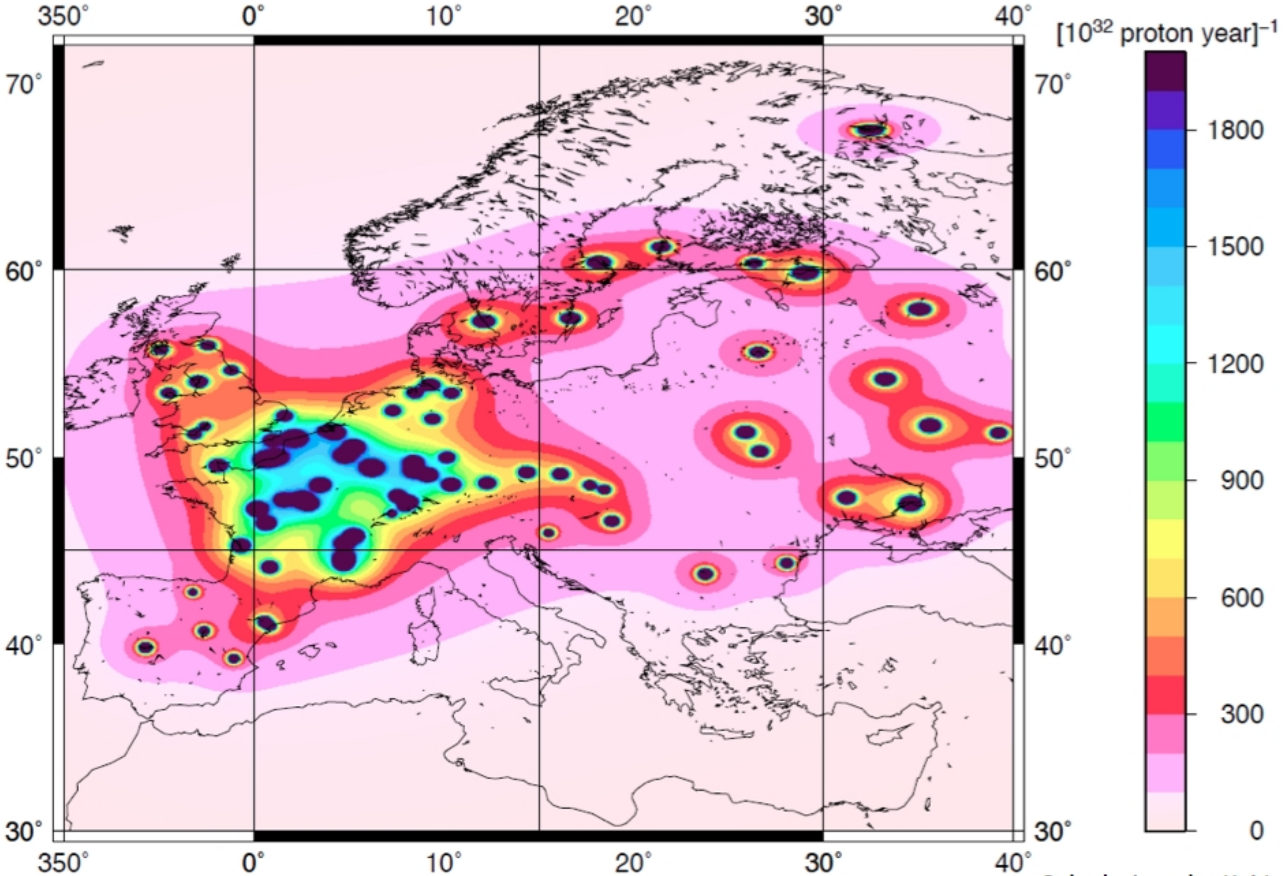
Long-Baseline Neutrinos





Reactor Neutrinos



Calculations by Kai Loo

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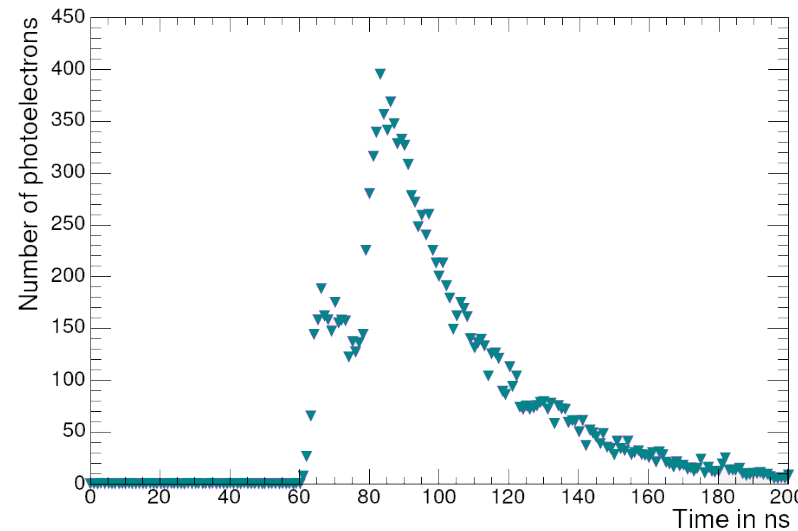
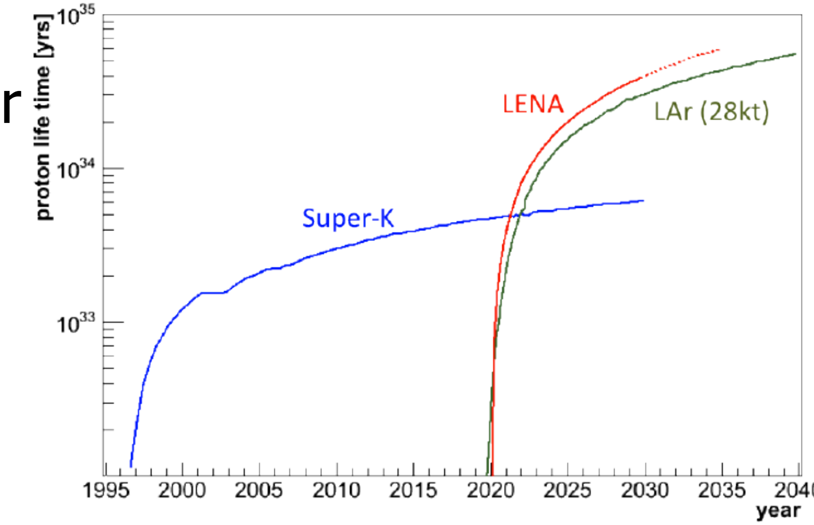
Proton Decay

LENA can set a limit of
$\tau_p > 4\text{x}10^{34}$ years in the channel

$$p \rightarrow K^+ + \bar{\nu}$$

- distinct pulse shape
- signal generated by kinetic energy deposition of kaon
- special for LS – Cherenkov threshold not reached in water
- prompt signal followed by signals from decay products
- background free for 10 years





Neutrino Detection in LS

Detection channels:

ν:

– elastic scattering $\nu + e^- \rightarrow \nu + e^-$

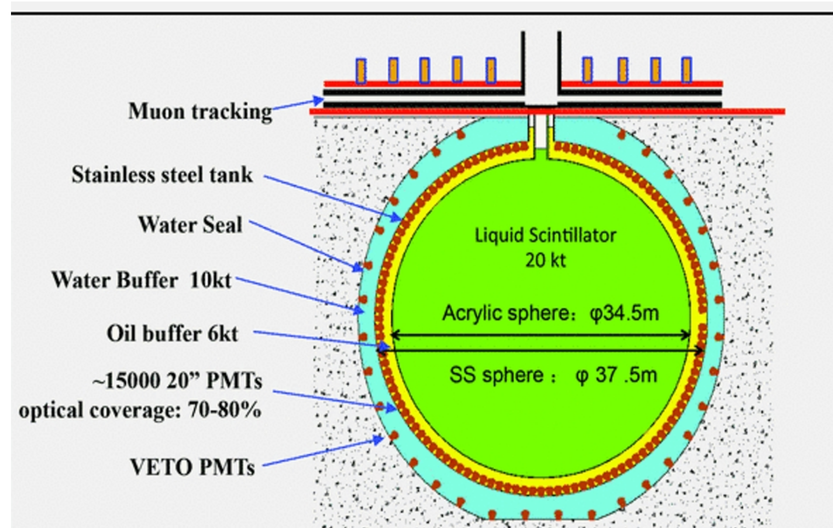
- proton recoil $\nu + p \rightarrow p + \nu$

- reactions on ^{12}C (NC and CC)

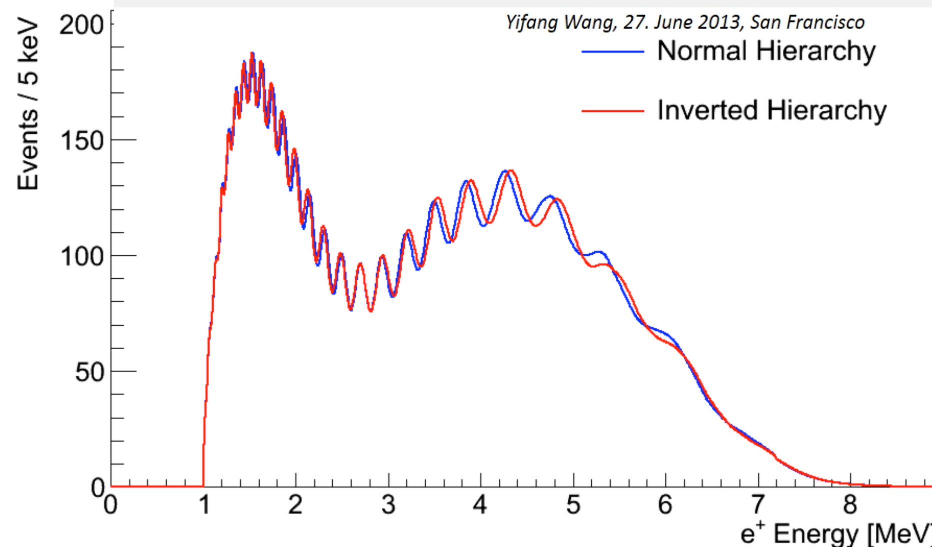
$\bar{\nu}_e$:

- inverse β-decay $\bar{\nu}_e + p \rightarrow e^+ + n$

JUNO?



JUNO liquid scintillator detector (schematic view)
RENO-2 follows a similar concept



How expensive is LENA?